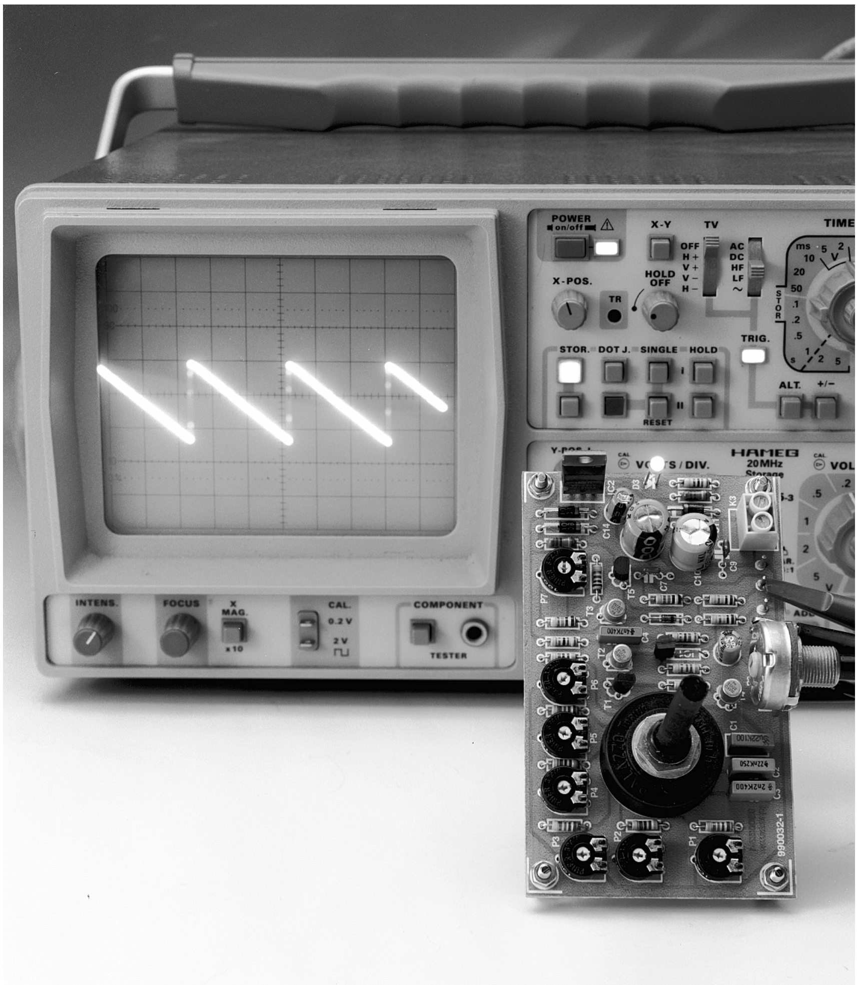
circuit testing with a sawtooth

audio measurements in theory and practice

Many experts in the field query the use of sinewave signals to test amplifiers and other audio gear. Although a rectangular signal is in principle suitable for many measurements, the sawtooth is believed by many to be a much better test signal. The combination of this test signal and an oscilloscope should enable you to give an expert opinion about audio equipment performance.



Specification

Waveform:	*inverted sawtooth*
Frequencies:	*100 Hz; 315 Hz; 1 kHz, 3.15 kHz, 10 kHz, 31.5 kHz*
Rise time	*<1% of period*
Linearity error	*<1%*
Output voltage:	*max. 3.5-4 V_{pp}*
Sync pulse:	*positive, max. 4 V_{pp}*
Power supply:	*12 V, approx 1.3 W*

Design by F. Hueber

When it comes to testing audio equipment with the aid of a sinewave signal, you first require a generator with very low distortion. Unfortunately, most function generators have a distortion between 1 and 3%, which makes them unsuitable for this particular application. AF generators of the Wien bridge type are to be preferred here because of their much better specification (distortion typically 0.01%). And yet, this distortion level may well be much higher than that of the equipment under test. What's more, measuring distortion and frequency response often equates to lots of individual measurements. Thing become even more complicated when you want to determine the dynamic range or overall stability of an amplifier under test. A simple sinewave signal, clean as it may be, is simply not suitable for that purpose. Likewise, judging the 'sonic quality' of, say, a power amplifier, is almost impossible with just a sinewave signal.

A pure sin-wave has a *crest factor* of 2 or about 1.41. The crest factor is the ratio of the peak value to the effective value. However, with music signals, or noise (percussion), this value can easily rise to 10 or higher. Consequently, an amplifier that performs very well under sinewave testing conditions may produce mediocre results when music or speech signals are applied.

This is due to the fact that a high-performance amplifier should be able to handle very fast signal rise times (often in the μs range) and still supply a clean output signal.

For music reproduction a frequency that just about covers the audible range (upper limit 16-20 kHz) is obviously too narrow. Good amplifiers these days go up to about 100 kHz, provided the slew rate is adequate. Again, these qualities are almost impossible to measure with just a sinewave.

Consequently, rectangular test signals are often used to put audio amplifiers through their paces, and subject them to some pretty gruelling tests. In practice, the response of an amplifier to rectangular signals says a lot about its sonic qualities. An advantage of the rectangular wave over the sinewave is its higher harmonics content. Consequently, you can do tests at the fundamental frequency of the rectangle signal as well as at much higher frequencies. It should be noted, however, that besides the fundamental frequency a rectangular wave contains only odd-numbered harmonics (3rd, 5th, 7th, etc.). So, a sawtooth signal would be even better. In principle, the sawtooth contains all harmonic frequencies (2nd, 3rd, 4th, 5th, etc.), again in addition to the fundamental frequency, so that the complete spectrum is always available.

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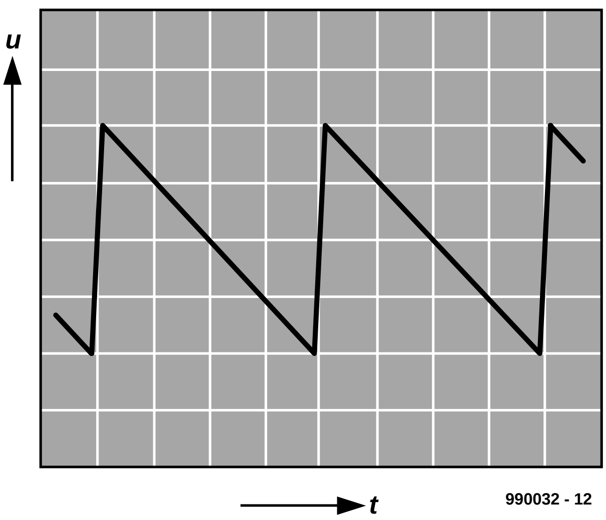

Figure 1. Negative (inverted) sawtooth.

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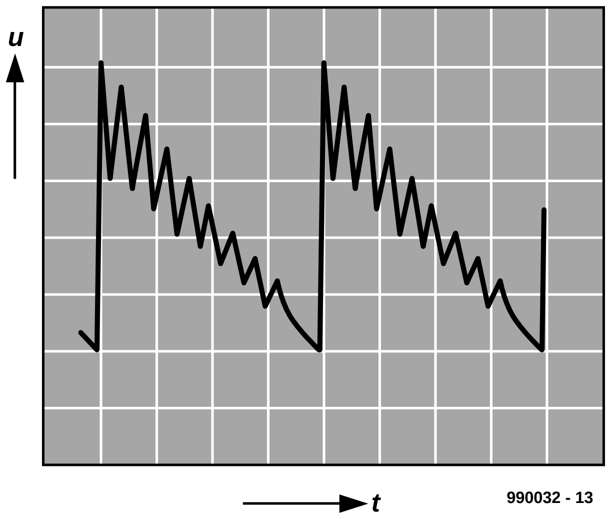

Figure 2. Amplifier suffering from a tendency to oscillate.

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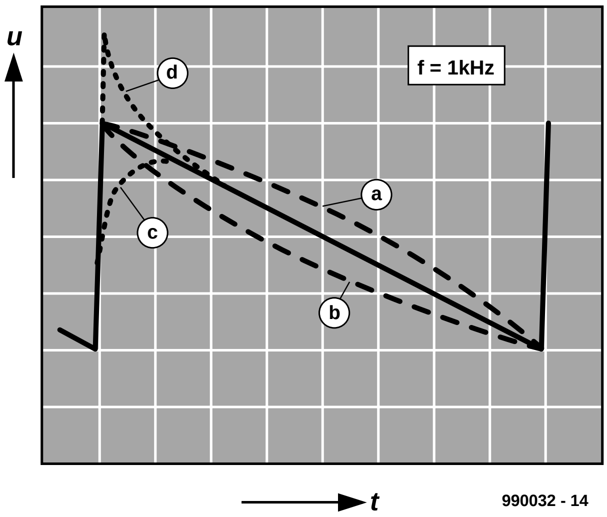


Figure 3. Effect on the frequency response.

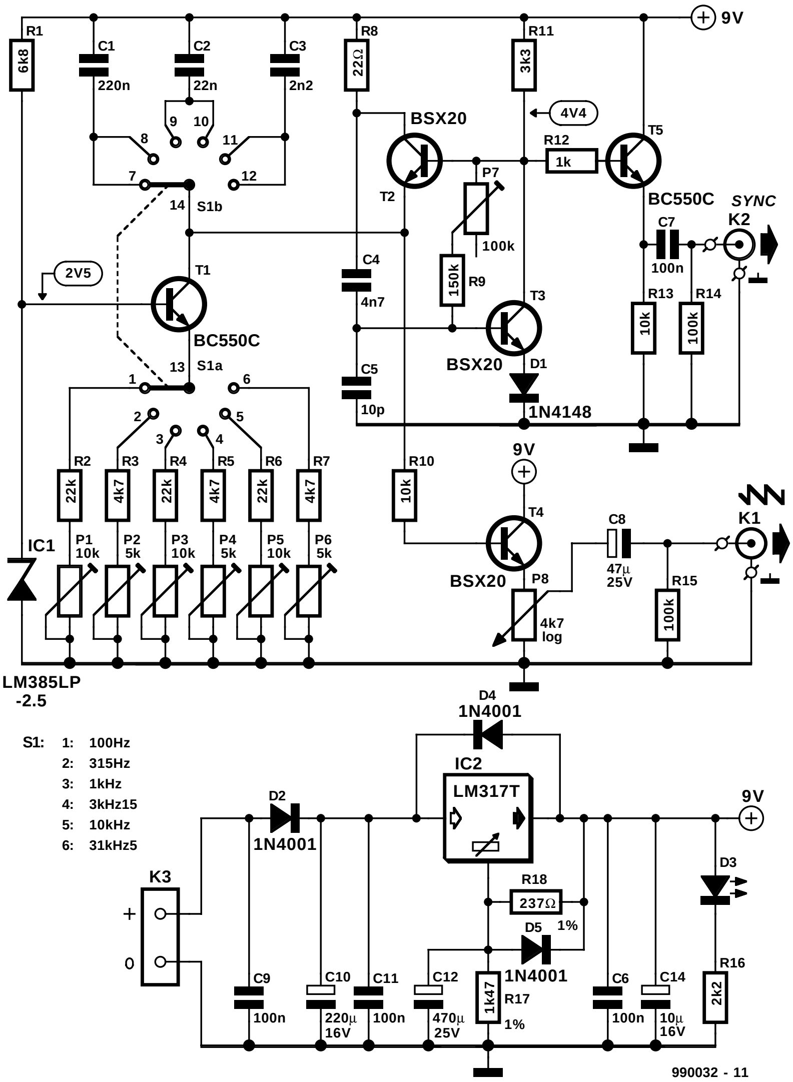


Figure 4. Circuit diagram of the simple sawtooth generator.

BETTER NEGATIVE THAN POSITIVE

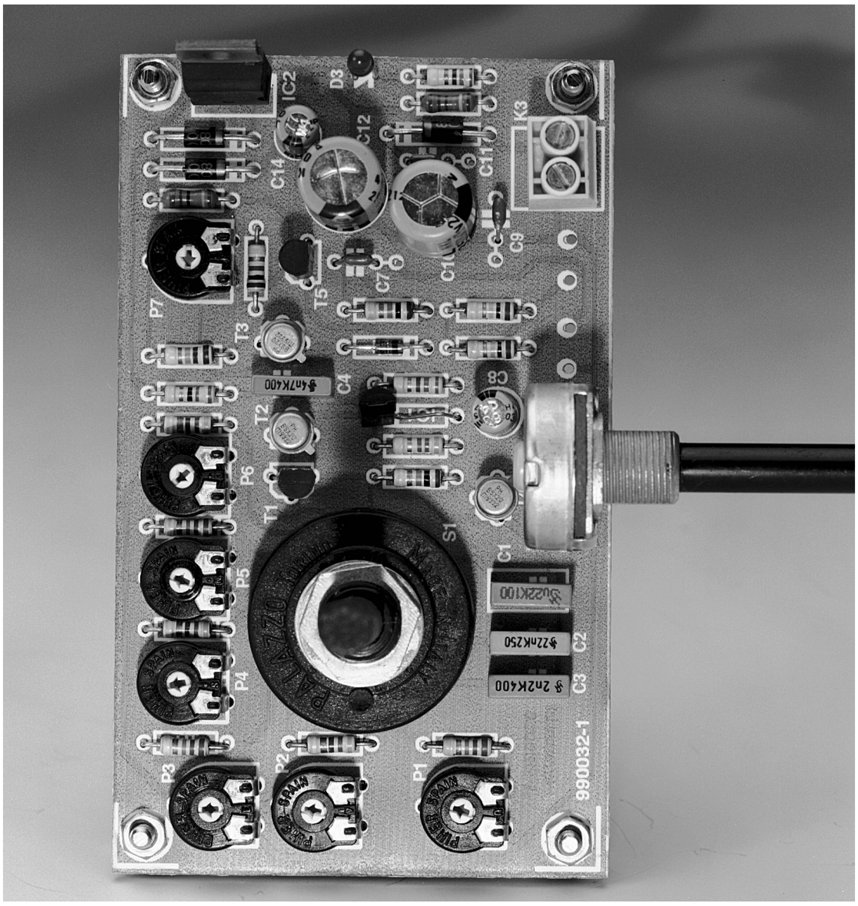
Unfortunately, the 'regular' (positive) sawtooth as supplied by many function generators is still not ideal when it comes to testing a wide range of audio equipment. One period of such a positive sawtooth signal consists of a slowly rising slope followed by a sharp falling edge. For our specific purpose, however, the inverted form, a 'negative' sawtooth, is better suited. Its shape is shown in **Figure 1**. Each period starts with a sharp rise, followed by a slow and gradual downward slope.

The main advantage of this waveform is that its fast edge will disclose any instability of the equipment under test. The oscilloscope picture in **Figure 2** shows the output signal of an amplifier with insufficient compensation for inductive loads. The tendency to oscillate is clearly visible.

Using a sawtooth test signal, only the best amplifiers will produce a faithful copy of the input signal, provided the frequency response is reasonably flat. After all, irregularities in the frequency response are also easily noticed if you use a sawtooth test signal. As shown in **Figure 3**, the effect is easily demonstrated on a tone control section when using a sawtooth test signal with a not too high frequency. If an amplifier or any other audio circuit has a (hidden) bass boost, the falling edge of the signal is slightly curved upwards (dashed line marked 'a'). If the low-frequency amplification is reduced, the falling edge 'droops' (b). If, by contrast, the equipment attenuates high frequencies, the upper part of the edge will be less steep, and the 'front' part of the signal becomes slightly curved (dotted line 'c'). Similarly, unwanted high-boost is indicated by this part being pulled up.

With a little practice, this measuring method can provide many interesting viewpoints concerning the functioning of amplifiers, filters and similar circuits. The sawtooth is also useful for those of you interested in testing and 'grading' cassette decks and other tape recording machines. For example, recording and playing back the 3.15-kHz test signal will provide lots of information on the optimum 'bias' level (pre-magnetisation) for a particular tape brand.

Another example is the compensation adjustment on a typical 10:1 oscilloscope probe — here, too, a sawtooth test signal results in easier and more accurate calibration than when the



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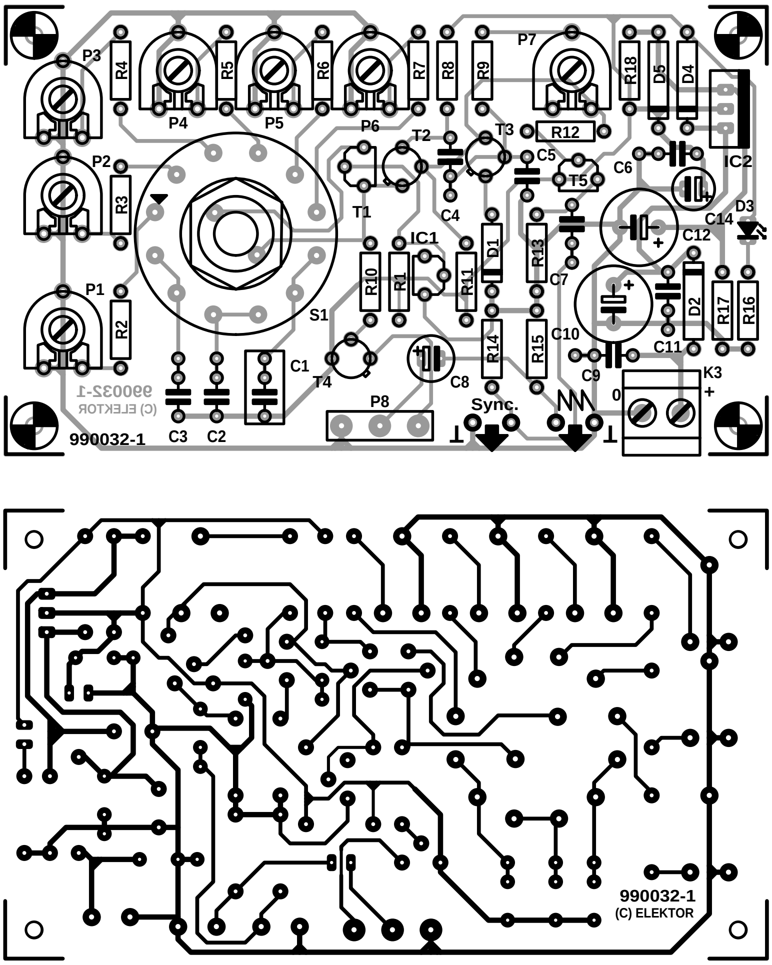

Figure 5. PCB design.

COMPONENTS LIST

Resistors:
R1 = 6kΩ8
R2,R4,R6 = 2kΩ2
R3,R5,R7 = 4kΩ7
R8 = 22Ω
R9 = 150kΩ
R10,R13 = 10kΩ
R11 = 3kΩ3
R12 = 1kΩ
R14,R15 = 100kΩ
R16 = 2kΩ2
R17 = 1kΩ47 1% metal film
R18 = 237Ω 1% metal film
P1,P3,P5 = 10kΩ preset
P2,P4,P6 = 5kΩ preset
P7 = 100kΩ preset
P8 = 4kΩ7 potentiometer, logarithmic

Capacitors:
C1 = 220nF
C2 = 22nF
C3 = 2nF2
C4 = 4nF7
C5 = 10pF
C6,C7,C9,C11 = 100nF
C8 = 47μF 25V radial
C10 = 220μF 16V radial
C12 = 470μF 25V radial
C14 = 10μF 16V radial

Semiconductors:
D1 = 1N4148
D2,D4,D5 = 1N4001
D3 = low-current LED
T1,T5 = BC550C
T2,T3,T4 = BSX20
IC1 = LM385LP-2.5
IC2 = LM317T

Miscellaneous:
S1 = rotary switch, 2 poles, 6 positions, PCB mount
K1,K2 = BNC socket, chassis mount
K3 = 2-way PCB terminal block, raster 5mm
PCB, order code 990032-1 (see Readers Services page).

flaky square wave from the oscilloscope itself is used.

Interesting and sometimes surprising facts may also be learned by first examining and comparing the output signal of an amplifier connected to a dummy load (i.e., a pure resistance), and then connect the output to a real-life load, that is, a loudspeaker. The results will clearly indicate why the combination (amplifier and loudspeaker) may not achieve a certain sonic quality, while there is nothing ostensibly wrong with the performance of the individual units.

An obvious requirement with all tests is that the equipment under examination is not overdriven. On the oscilloscope, overdriving is indicated by rounded signal tops (‘clipping’), just as with any other waveform. The sawtooth waveform is then transformed in a trapezoid voltage, and everything mentioned so far is then subject to more than one serious limitation.

The desired waveform called ‘negative sawtooth’ may, of course, be obtained from any generator with a positive sawtooth output, simply by inverting the signal. However, doing so may cause problems with the signal linearity and rise time. In general, it will be better to use a purpose designed generator, and such an instrument is described here.

A SIMPLE SAWTOOTH GENERATOR

Although a negative sawtooth is eminently suited as a test signal, this particular waveform is rarely found on commercial function generators and similar instruments. The simple generator described here requires only a handful of commonly available parts, yet guarantees excellent performance.

As shown in **Figure 4**, the generator proper is built from discrete parts only, including transistors. Together with voltage reference element IC1, transistor T1 acts as a constant-current source. Depending on the frequency range selected with switch S1, one of the potentiometer-resistor combinations causes a certain constant current to be generated in the emitter line of T1. This current is used to charge capacitors C1, C2 and C3. Each of these is responsible for two frequency ranges. Once the voltage across the capacitor reaches the turn-on level of T2, this transistor starts to conduct, the collector current generating a ‘dip’ at current limiter resistor

Harmonics

Harmonics are oscillations of a periodic quantity, present in a complex signal, having a frequency that is an integral multiple of the fundamental frequency. A sinewave signal should be as pure as possible, which means that it should have as few as possible harmonics. If harmonics are present, they should have the lowest possible level (small distortion). The actual number of harmonics associated with a sinewave, and in particular their level, is strongly dependent on the elementary design of the generator, as well as on components used, and is difficult to predict.

By contrast, the waveform supplied by rectangular-wave and sawtooth generators is accurately determined by the number of harmonics, at least the lower-order ones, and the harmonic levels may be calculated approximately. As a rule of thumb, the discrete level of a harmonic is the reciprocal of the number of harmonics, multiplied by the level of the fundamental signal. In an equation,

$$V_H = (1/n) \times V_F$$

where

V_H = *level of harmonic*
n = *number of harmonic (2, 3, 4, …)*
V_F = *level of fundamental signal*

For example, assuming you have a available a 1-kHz signal with a level of 3 V, the level of the 4th harmonic equals

$$V_H = (1/4) \times 3 = 0.75\ \text{V}$$

Expressed in decibels (dB) this equates to

$$20 \log (3/0.75) = 12\ \text{dB}$$

below the level of the fundamental frequency.

R8. Via capacitor C4 this dip arrives at transistor T3, causes it to block, so that its collector and the base of T2 will be pulled to a high potential. This potential change causes T2 to conduct abruptly, allowing the selected capacitor to be rapidly discharged.

The sawtooth generator employs an old faithful: the BSX20 transistor, a fast switching device which has been with us for more than 25 years. General-purpose AF transistors are used in the constant-current source and the synchronisation driver stage. Thanks to the above mentioned feedback, the sawtooth is characterised by extremely short rise times.

Diode D1 lifts the emitter potential of T3 by a constant level above ground, enabling the base to become more negative than the emitter. In this way, the transistor can be switched off rapidly and completely. For proper functioning of the circuit it is necessary to have a defined potential at the collector of T3. Preset potentiometer P7 allows this potential to be adjusted, independent of the current gain of T3.

By way of decoupling resistors R10, the sawtooth voltage at the emitter of T2 is fed to emitter follower T4. The output voltage is taken from the wiper of potentiometer R8 in the emitter line. Via C8, the output signal arrives dc-free at output socket K1. To enable small output voltage levels to be set with sufficient accuracy, pot P8 should be a logarithmic type.

The feedback pulse supplied by T3 is fed to sync output socket K2 by way of another emitter follower, T5. The sync signal appears at the same time as the rising edge of the sawtooth, and is useful to keep an oscilloscope triggered.

The mains power supply is a conventional design. Because of the low current drain, a small (single-winding) transformer is sufficient, together with a single-phase rectifier and a fairly large smoothing capacitor, C10, for ripple suppression. Alternatively, the transformer and rectifier may be replaced by a low-power mains adaptor (cheaper and safer).

Because the stability and purity of the supply voltage affect the quality of the output voltage, the voltage regulator section is a bit more extensive than usual. The stabilising element, an LM317, is set to supply an output voltage of 9 V by means of R17 and R18. The Adj(ust) input of the LM317 has an additional decoupling capacitor, C12. The resulting output voltage is cleaner and much more stable than would be possible when using, say, a 7809 fixed-voltage regulator. The LM317 has to be fitted with a small heatsink.

Without LED D3, the circuit draws about 3.5 mA. Include the LED and the current still remains low at about 13.5 mA. Because the generator can work off a 5-V supply without major modifications to the circuit, battery-powering using a 9-V PP3 block is a feasible option. Resistors R17 and R18 then have to be changed accordingly. Also, because the indicated frequencies are roughly doubled at a supply voltage of 5 V, resistors R2-R6 have to be suitably modified (i.e., their value has to be increased).

CONSTRUCTION AND ADJUSTMENT

To keep unwanted signals out of the circuit, the generator is best fitted in a metal enclosure with (approximate) dimensions 150x60x100 mm.

Building up the circuit board shown in **Figure 5** should not present problems, we reckon, because only a few common parts are involved. However, do make sure you fit the polarized components the right way around; these include the electrolytic capacitors, diodes and transistors in TO18 case (emitter marked by a small locating tab). The circuit is powered by a small mains adapter capable of supplying at least 12 V d.c.

Having switched on the circuit, the first thing to do is check the presence of the reference and supply voltages. Next, P7 is adjusted to give a collector voltage of between 4.3 V and 4.5 V on T3. This is an important adjustment because it determines to a large extent the frequency calibration, output signal level and the total functioning of the generator.

Next, adjust P1-P6 to give the desired frequencies, using a frequency meter connected to output K1. Preset P7 should not be adjusted again at this stage because all frequency settings depend on it.

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